Ontario

Ministry of Transportation
Materials Engineering and Research Report

Falling Weight Deflectometer (FWD) Testing Guideline

MERO-019

Technical Report Documentation Page

Publication Title	# Falling Weight Deflectometer (FWD) Testing Guideline

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Abstract	Falling Weight Deflectometer (FWD) testing is a non-destructive method for evaluating the structural capacity of a pavement structure. Ministry of Transportation Ontario (MTO) developed this FWD Testing Guideline to promote consistent application of FWD testing work throughout the province. This report consists of general descriptions of the FWD testing process, the minimum equipment calibration requirements, the FWD testing deliverables, and how to assess the FWD data. This guideline also contains various FWD testing protocols to enhance precision and accuracy of the FWD testing methodology. In addition, general contract administrative requirements and a sample Terms of Reference are provided to assist with consultant assignment preparation.

Key Words	FWD, Falling Weight Deflectometer
Distribution	Unrestricted technical audience.

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Executive Summary

Falling Weight Deflectometer (FWD) testing is a non-destructive method for evaluating the structural capacity of a pavement structure. It is a useful tool for pavement evaluation and monitoring, at both the network and project levels, for the Ministry of Transportation Ontario (MTO).

The Ministry identified a need for a comprehensive standard test procedure for FWD testing. This FWD Testing Guideline was developed to promote consistent application of FWD testing work throughout the province.

This guideline contains general descriptions of the FWD testing process, the minimum equipment calibration requirements, the FWD testing deliverables, and how to assess the FWD data. Various FWD testing protocols are also included in the guideline to enhance precision and accuracy of the FWD testing methodology. Additionally, general contract administrative requirements and a sample Terms of Reference are provided to assist with consultant assignment preparation.

Introduction

Falling Weight Deflectometer (FWD) testing is a non-destructive method for evaluating the structural capacity of a pavement structure. This FWD Testing Guideline promotes the consistent application of FWD testing work throughout the province by specifying various FWD testing protocols to enhance precision and accuracy of the methodology.

This FWD Testing Guideline is applicable for flexible (hot mix asphalt), rigid (Portland cement concrete) and composite (hot mix asphalt and Portland cement concrete) pavements.

Equipment Specifications

This section addresses the FWD equipment specifications including the minimum equipment calibration requirements, and provides a list of companies that own FWD equipment in Canada as of May 2004.

In general, the FWD equipment should consist of the following components and comply with the specification described below [1]:

- **Load Pulse** with target peak load of 75 +/- 5 kN.
- **Loading Plate** with a rubber pad of at least 5 mm thickness glued to the bottom to allow uniform load application onto the pavement surface. Rubber pads must meet the equipment manufacturers specifications requirements.
- A minimum of seven **Deflection Sensors** with radial line distances from 0 to 180 cm.
- **Load Cell** with reading resolution of 0.1kN or better.
- **Thermometer** with reading resolution of 0.5 °C or better.

LIST OF FWD EQUIPMENT

The following Canadian organizations own FWD equipment, as of May 2004:

- EBA Engineering (3)
- J.R. Payne (1)
- Pavement Scientific International, Inc. (1)
- Trow (1)
- JEGEL (1)
- ERES (7)
- MTQ (1)
- CRCAC (1)
- Laval University (1)
- Stantec (5)
- Golder Associates (1)

The following companies as illustrated in Table 1 provide FWD testing services in Ontario, as of May 2004:

Table 1 – FWD Testing Services Companies in Ontario

Company	Contact Person	Phone	Fax
JEGEL – Dynatest Unit 1, 109 Woodbine Downs Blvd Etobicoke, Ontario, M9W 6Y1	Mike MacKay Dave Soanes jegel@jegel.com	416-213-1060	416-213-1070
Trow Consulting Engineers Ltd. 1595 Clark Blvd. Brampton, Ontario, L6T 4V1	Stephen Lee Stephen.lee@trow.com	905-793-9800 x 2209	905-793-0641
ERES Consultants 5401 Eglinton Ave. W., Suite 204 Toronto, Ontario, M9C 5K6	Dave Hein dhein@ara.com	416-621-9555 x 1	416-621-4917
Stantec 49 Frederick Street, Kitchener, Ontario, N2H 6M7	Zaubair Ahmed zahmed@stantec.com Andy Dalziel adalziel@stantec.om	519-585-7463	519-579-6733
Golder Associates Ltd 100 Scotia Court Whitby, ON, Canada L1N 8Y	Andrew Balasundaram abalasundaram@golder.com	905-723-2727	905-723-2182

EQUIPMENT CALIBRATION

Periodic calibration of the FWD equipment ensures the accuracy of the FWD testing. There are four certified calibration centers established by the Strategic Highway Research Program (SHRP) to provide calibration services for the FWD equipment that comply with the procedure in Appendix A of SHRP Report SHRP-P-661. The calibration centers were opened in cooperation with State Departments of Transportation (DOTs) in the following locations [2]:

- Minnesota, Colorado, Pennsylvania and Texas.
- Contact information for each center is available at: http://www.tfhrc.gov/pavement/ltpp/fwdcont.htm

The full FWD equipment calibration is a two-part procedure which includes [3]:

- **Reference Calibration**
  - To calibrate the FWD machine against an independent reference system.
- **Relative Calibration**
  - To calibrate the deflection sensors against each other.

As a minimum, full calibration (both reference and relative) is required annually at one of the four certified calibration centres. Reference calibration shall be performed annually; relative calibration shall be performed on a monthly basis. A full calibration is also required immediately after replacement of a load cell or replacement of any major components of the FWD equipment, such as deflection sensors, signal processing module, etc.

The Consultant shall submit an up-to-date calibration report prior to any FWD testing. The servicing date shall be within one year after the date of full calibration. The full FWD certification of calibration report should consist of the following:

- Print out of the FWD field program screen including:
    - FWD identification and calibration date
    - Transducer set-up and calibration factors
    - Voltages
    - Load cell calibration.
- All printouts from the FWDREFEL software.
- The final printouts from the FWDCAL2 software for all relative calibration trials.
- The final calibration computation worksheet.

Testing Protocols

This section specifies various FWD testing protocols which identify the testing location and frequency requirements, as well as the external factors that might influence the results of the FWD testing which require special attention.

TYPES OF FWD TESTING

FWD testing can be performed on numerous pavement structures (i.e., flexible, rigid and composite pavements) and there are two main types of FWD testing as illustrated below:

- **Deflection Basin Test**
  - Test on all types of pavement structures.
  - Analyzed to estimate in-situ characteristics of the materials in the pavement structure (structural adequacy).
- **Load Transfer Test**
  - Test at joints and cracks on Portland Cement Concrete (PCC) pavements.
  - Analyzed to evaluate load transfer efficiency across the joints and cracks.
  - Evaluate the possible existence of voids under the pavement.

DATA COLLECTION SCENARIOS

Depending on the usage of the FWD testing data, the test protocols should be adjusted accordingly. Three types of data collection scenarios are illustrated below [4]:

- **Network Level**
  - Typically performed at 200 m to 500 m intervals.
  - Minimum of 7 test points per uniform pavement section is recommended to ensure a statistically significant sample.
  - Minimum of 1 load drop at each load level.
  - In general, at least 10% of the slabs should be tested at the joints for Jointed Concrete Pavement (JCP).
- **General Project Level**
  - Typically performed at 50 m to 200 m intervals.
  - Minimum of 15 test points recommended per uniform pavement section.
  - Minimum of 1 load drop at each load level.
  - In general, minimum joint coverage rate of 25% is recommended for Jointed Concrete Pavement (JCP).
  - Detailed breakdown of testing frequency at cracks or joints [5]:

        - Cracks in Jointed Reinforced Concrete Pavement (JRCP)
            - 10% of all cracks 10 - 13 mm in width
            - 25% of all cracks 13 - 25 mm in width
        - Cracks in Jointed Plain Concrete Pavement (JPCP)
            - 25% of all cracks 10 - 13 mm in width
        - Joints[1]
            - 10% of low severity joints
            - 25% of medium severity joints
            - 10% of high severity joints
- **Detailed Project Level**
    - Typically performed at 10 to 50 m intervals.
    - Minimum of 20 test points recommended per uniform pavement section.
    - Minimum of 1 to 2 load drops at each load level is recommended.
    - In general, minimum joint coverage rate of 50% is recommended for Jointed Concrete Pavement (JCP).
    - Detailed breakdown of testing frequency at cracks or joints [5]:
        - Cracks in Jointed Reinforced Concrete Pavement (JRCP)
            - 10% of all cracks 10 - 13 mm in width
            - 75% of cracks 13 - 25 mm in width (100% if asphalt concrete overlay present)
        - Cracks in Jointed Plain Concrete Pavement (JPCP)
            - 100% of all cracks 10 - 13 mm in width
        - Joints[1]
            - 10% of low severity joints
            - 50% of medium severity joints (75% if asphalt concrete overlay present)
            - 10% of high severity joints

As a rule, cracks less than 10 mm wide or wider than 25 mm shall not be FWD tested. Appropriate testing protocols should be utilized accordingly for each of the aforementioned data collection scenarios.

VARIOUS TESTING PROTOCOLS

FWD testing can be performed on many combinations of pavement structures, and test plan modification is required to accommodate for different types of testing. The typical FWD test plans which apply to different types of pavement structures are tabulated below:

1 Joint severity relates to the presence and severity of distresses such as joint failure, spalling, faulting and corner cracking as defined in the Ministry's Manual for Condition Rating of Rigid Pavements, SP-026.

Table 2 – FWD Test Plan

FWD Test Plan	Combination of Pavement Structures
FLEX (Flexible Pavement)	AC Pavement Over Granular Base (AC/AGG) AC Pavement Over Stabilized or Treated Base (AC/BTB or CTB) AC Overlay of AC Pavement (AC/AC) AC Overlay of PCC Pavement (AC/PCC)
JCP (Rigid Pavement)	Joint Plain Concrete Pavement (JPCP) Jointed Reinforced Concrete Pavement (JRCP) Unbonded PCC Overlay of PCC Pavement (PCC/PCC) Bonded PCC Overlay of PCC Pavement (PCC/PCC)

- FLEX Test Plan
  - Typically, an automated seating load, then three target load drops of 40 kN, 55 kN and 70 kN are sufficient to carry out the test and analysis.

- JCP Test Plan
  - Typically, an automated seating load, then three different target load drops at 40 kN, 55 kN and 70 kN.

In general, the **sensor configurations** are standardized in the following formats for the deflection basin test and load transfer test [5]:

- Deflection Basin Test:
  - 0, 20, 30, 45, 60, 90, 150 cm

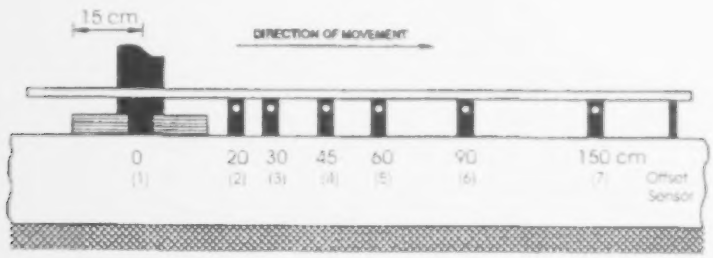


Figure 1 - Typical 7 Sensors Configuration for FWD Deflection Basin Test

- Load Transfer Test:
  - –30, 0, 30, 45, 60, 90, 150 cm

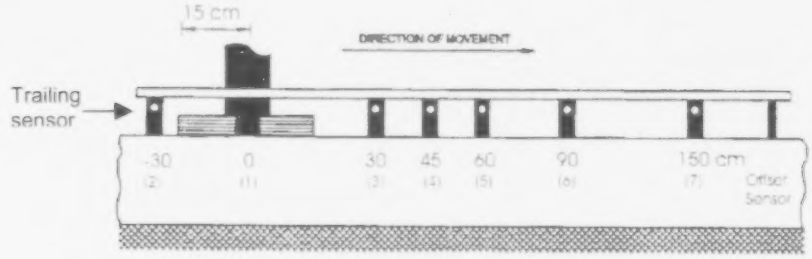


Figure 2 - Typical 7 Sensors Configuration for FWD Load Transfer Test

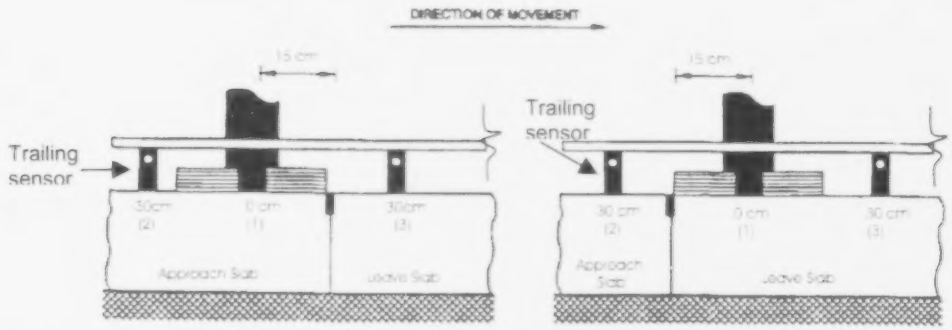
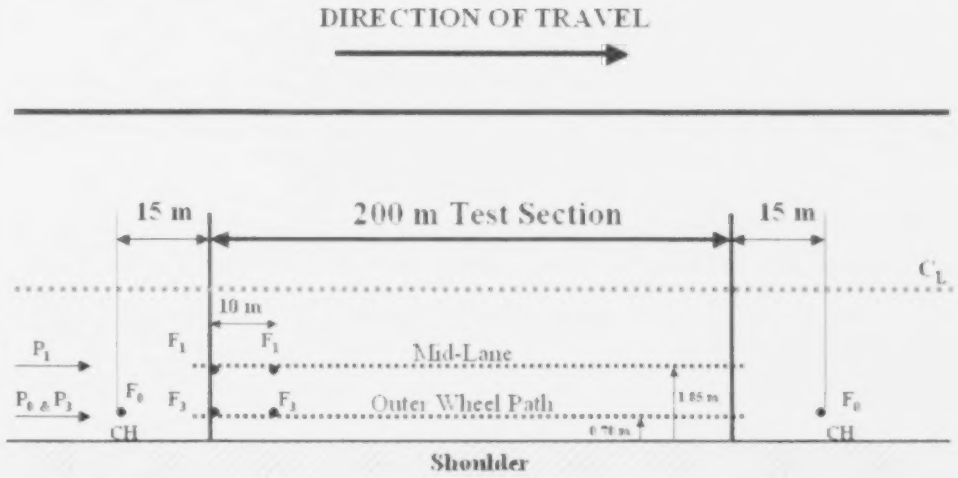


Figure 3 - Typical Sensor Configuration for FWD Load Transfer Test (Approach and Leave Slab)

Following are two **sample testing protocols** for the test plans previously discussed [5]. These test plan protocols are based on a ***detailed project level*** data collection scenario with an average of 10-metre test point interval. This is the **maximum recommended** FWD testing configuration for all test section. Adjustment is required accordingly when applying the test to other data collection scenarios (i.e. *network level* and *general project level)*. Refer to previous section, *Data Collection Scenarios* for testing frequency on different data collection requirements.

A minimum of two boreholes/coreholes, small diameter pilot hole, should be taken as illustrated below. Coreholes should not be drilled within the test section, and a minimum distance of 15 m away from the test section boundary. Coreholes are taken to determine pavement temperature and/or pavement layer thickness to better correlate the FWD testing result.

DETAILED PROJECT LEVEL - FLEX TEST PLAN CONFIGURATION



Notes: ***NOT TO SCALE***

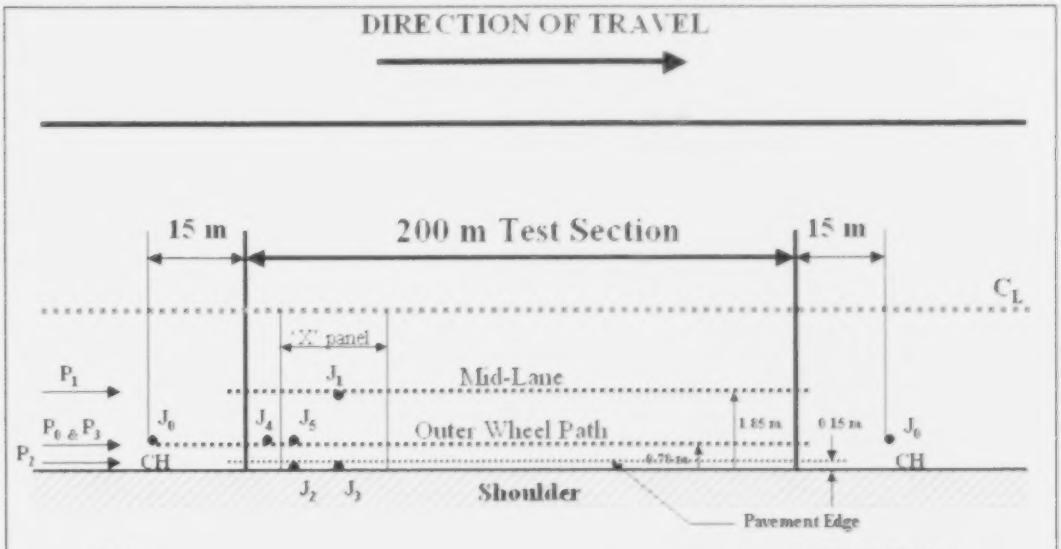
FWD tests (F_0) to be conducted at corehole/borehole locations (CH) on the first pass (P_0).
Two additional passes shall be made; one at midlane (P_1) and one in outer wheel path (P_3).
The testing interval for passes P_1 and P_3 is 10 m for a total of 21 tests (F_1 and F_3) per pass.
Lateral offsets shown represent nominal distances to midlane and outer wheel path.
See Table 3 (below) for details.

Figure 4 - Typical FLEX Test Plan Configuration (Detailed Project Level)

Table 3 - Summary of Typical FLEX Test Plan Configuration (Detailed Project Level)

Test Point	Pass No.	Location		Test Interval	Test Type	Sensor Configurations (cm)	No. of Test Points
		Transverse	Longitudinal				
F_0	P_0	Outer Wheelpath	Core /Borehole	N/A	Basin	0, 20, 30, 45, 60, 90, 150	2
F_1	P_1	Mid Lane	--	10 m	Basin	0, 20, 30, 45, 60, 90, 150	21
F_3	P_3	Outer Wheelpath	--	10 m	Basin	0, 20, 30, 45, 60, 90, 150	21

DETAILED PROJECT LEVEL - JCP TEST PLAN CONFIGURATION



Notes: ***NOT TO SCALE***

FWD tests (J_0) to be conducted at corehole/borehole locations (CH) on first pass (P_0).
Stationing will vary to locate CH at mid-panel.
Three additional passes shall be made; one at mid-lane (P_1), one at pavement edge (P_2) and one in the outer wheel path (P_3).
Tests in mid-lane along P_1 shall be carried out at mid-panel (J_1).
Tests at pavement edge along P_2 shall be carried out at the leave side of joint (J_2) and mid-panel (J_3).
Tests in the outer wheel path along P_3 shall be carried out on either side of the joint (J_4 & J_5).
Number of panels and panel length (X) will vary depending upon specific joint spacing, transverse crack pattern and pavement type. Test a maximum of 20 effective slabs (panels).
Lateral offsets shown represent nominal distances to mid-lane, outer wheel path and edge.
See Table 4 (below) for details.

Figure 5 - Typical JCP Test Plan Configuration (Detailed Project Level)

Table 4 – Summary of Typical JCP Test Plan Configuration (Detailed Project Level)

Test Point	Pass No.	Location		Test Interval	Test Type	Sensor Configurations (cm)	No. of Test Points
		Transverse	Longitudinal				
J_0	P_0	Outer Wheelpath	Core/ Borehole	N/A	Basin	0, 20, 30, 45, 60, 90, 150	2
J_1	P_1	Mid Lane	Mid Panel	See Note	Basin	0, 20, 30, 45, 60, 90, 150	20
J_2	P_2	Pavement Edge	Corner	See Note	Basin	0, 20, 30, 45, 60, 90, 150	20
J_3	P_2	Pavement Edge	Mid Panel	See Note	Basin	0, 20, 30, 45, 60, 90, 150	20
J_4, J_5	P_3	Outer Wheelpath	+/- Joint	See Note	Load Transfer	-30, 0, 30, 45, 60, 90,150	40

Typically for FWD testing at the *Network Level* and *General Project Level* testing is only required for one pass along the outer wheel path with staggered locations in the heaviest loaded lane. Once again, the test plans are the **maximum** FWD test points configuration for reference purpose. The number of test points required for individual projects shall be determined and referenced to the *Data Collection Scenarios* and the aforementioned test plans. The number of test points required shall be specified in the Terms of Reference accordingly for hiring a consultant.

EXTERNAL FACTORS INFLUENCING THE ACCURACY OF FWD TESTING

This section identifies the external factors that would affect the accuracy of the FWD testing and describes considerations and an operational procedure that shall be used to minimize errors [5].

FACTORS AFFECTING FWD TESTING

- Environmental factors
  - Temperature and moisture affect deflection response
- Pavement factors
  - Layer thickness, layer material type, material quality and subgrade support

FACTORS TO CONSIDER TO MINIMIZE ERRORS

- Calibrate FWD equipment (Refer to previous *Equipment Calibration* for details)
  - Reference Calibration (annually)
  - Relative Calibration (monthly)
- Technical operator should be able to demonstrate the work required for FWD testing
- Use seated load drops
- Use multiple load drops
- Use reliable pavement structure data for back calculation
  - Layer thickness, type
  - Subgrade type

FWD OPERATIONAL PROCEDURE TO MINIMIZE ERRORS

- FWD testing should be conducted in an air temperature range from 0 to 20° C
- Avoid testing when there is still frost in the ground or any free water in the various layers of the road structure
- Identify the location of test points with respect to physical location (i.e., marking along the edge of pavement) for future reference
- Operator should not "bias" deflection readings by testing only crack-free areas or only cracked areas

- Test location shall be free from all rocks and debris to ensure loading plate is properly seated

APPROXIMATE UNIT COSTS FOR FWD TESTING

Cost associated with FWD testing services can vary depending on highway facility type, day or night work, operational constraints required for traffic control, points of mobilization, and type of FWD testing being conducted, etc.

The approximate unit cost for doing FWD testing is identified for your reference based on MTO regional experience as of 2004, excluding the cost for traffic control. All prices are inclusive with interpretation of results, reports, and quality control, etc.

• Mobilization to Job Site	$2.00 to 5.50 / km
• Daily Expense for the Field Crew	$150.00 / day
• FWD Deflection Basin Test	$20.00 to 25.00 / test point

TRAFFIC CONTROL

All work carried out shall comply with **Ontario Traffic Manual Book 7**. The Consultant is to submit a Health and Safety Plan and moving traffic control plan prior to FWD testing.

FWD Testing Deliverables

This section discusses the typical output and analysis requirements that shall be submitted by the Consultant following the FWD testing.

The Consultant shall submit FWD raw data files (unedited data files in electronic *.fwd, f25, f20 format or equivalent) immediately following completion of testing.

FWD TESTING OUTPUT

A typical FWD deflection testing report should consists of the following outputs [5]:

- Description of project
- Date and time of test
- Operator identification
- Vehicle information
- Weather conditions
- Air and pavement temperature
- Location and Section information
    - Starting point reference (station or fixed reference)
    - Direction of travel
    - Lane being tested
- Type of pavement being tested
- Type of deflection test
    - Deflection basin
    - Load transfer
- Location of sensors
- Applied load and load frequency
- Measured deflections under load

FWD TESTING ANALYSIS

The Consultant shall collect and manipulate the raw data into a format suitable for data analysis and interpretation using up-to-date SHRP or AASHTO approved back-calculation software. The back-calculation software utilized shall be capable of providing the modulus of each pavement structure layer. The more commonly used FWD back-calculation software are listed below:

FWD BACK-CALCULATION SOFTWARE

- BISDEF, ELSDEF, CHEVDEF, MODULUS, COMDEF, WESDEF, WESLEA, ELYSM5, MODCOMP, BOUSDEF, **ELMOD**, **EVERCALC** and ILLI-BACK

- **EVERCALC** is fairly user-friendly software that reads most Dynatest FWD equipment files. It is available free from Washington State Department of Transportation.
    - http://www.wsdot.wa.gov/biz/mats/pavement/fwd.htm

- **ELMOD** from Dynatest is the most common software used by Canadian agencies. It is owned by four of five local FWD providers: JEGEL, Trow, ERES and Golder. MTO Pavements and Foundations Section also has a copy of ELMOD.

Most of the back-calculation software can manipulate the data to provide the layer moduli for each layer of the pavement structure. To facilitate the pavement back-calculation analysis, the pavement layer material type and thickness, as well as the depth to bedrock or stiff layer information are essential. This layer modulus can then be used to determine the structural adequacy of the pavement and thus estimate the expected life to analyze for future rehabilitation strategies. Following are the typical deliverables required from the consultant through data manipulation:

FWD TEST ANALYSIS OUTPUT DELIVERABLES

- Deflection Basin Test:
    - Normalized Dynamic Deflection at 0 cm offset (40 kN load and 21°C asphalt temperature)
    - Maximum and Differential Deflection
    - Individual Pavement Layer and Subgrade Moduli
    - Individual Pavement Layer Granular Base Equivalency (GBE)
    - Average Deflections and Moduli for each test section

- Load Transfer Test (PCC pavement only):
    - Load Transfer Efficiency (LTE %) over the specified section of pavement
    - Loss of Support / Void Detection Analysis

SAMPLE GUIDELINE TO DETERMINE CONCRETE REPAIR USING FWD TESTING

A sample guideline to determine concrete repair strategies based upon the load transfer efficiency and visual inspection survey is included for reference.

Following are the sample guideline developed by Central Region to determine the most efficient concrete repair treatment for various PCC pavements based upon [4]:

- FWD testing result of load transfer efficiency (LTE %)
- Visual condition of the crack and joint severities

Table 5 - Criteria for Full Depth Concrete Repair of Transverse Cracks in JRCP

LTE	JRCP - Transverse Crack Width		
	< 13 mm	13-25 mm	>25 mm
>70%	Full Depth Repair NOT Required	[2]Consider other data to determine repair	Full Depth Repair
50-70%	[2]Consider other data to determine repair	Full Depth Repair	Full Depth Repair
<50%	Full Depth Repair	Full Depth Repair	Full Depth Repair

Table 6 - Criteria for Full Depth Concrete Repair of Transverse Cracks in JPCP

LTE	JPCP - Transverse Crack Width		
	< 13 mm	13-25 mm	>25 mm
>70%	[2]Consider other data to determine repair	Full Depth Repair	Full Depth Repair
50-70%	Full Depth Repair	Full Depth Repair	Full Depth Repair
<50%	Full Depth Repair	Full Depth Repair	Full Depth Repair

2 Consider other data to determine repair including:
- Visual assessment for the presence and severity of crack-related distresses such as faulting, spalling and corner cracking
- Loss of support / void detection analysis from FWD testing

Table 7 - Criteria for Full Depth Concrete Repair of Dowelled Joints in JRCP and JPCP

LTE	Joint Severity[3] – JRCP and JPCP		
	Low	Medium	High
>70%	Full Depth Repair NOT Required	[4]Consider other data to determine repair	Full Depth Repair
50-70%	[4]Consider other data to determine repair	Full Depth Repair	Full Depth Repair
<50%	Full Depth Repair	Full Depth Repair	Full Depth Repair

The above tables provide a guideline for concrete repair after obtaining the data from FWD testing analysis. Concrete repair should be determined base on the distinct condition of the concrete joints and cracks on the individual project, with reference to the concrete repair guideline.

3 Joint severity relates to the presence and severity of distresses such as joint failure, spalling, faulting and corner cracking as defined in the Ministry's Manual for Condition Rating of Rigid Pavement, SP-026.

4 Consider other data to determine repair including:

- Visual assessment for the presence and severity of crack-related distresses such as faulting, spalling and corner cracking
- Loss of support / void detection analysis from FWD testing

SAMPLE FWD TESTING DATA ANALYSIS

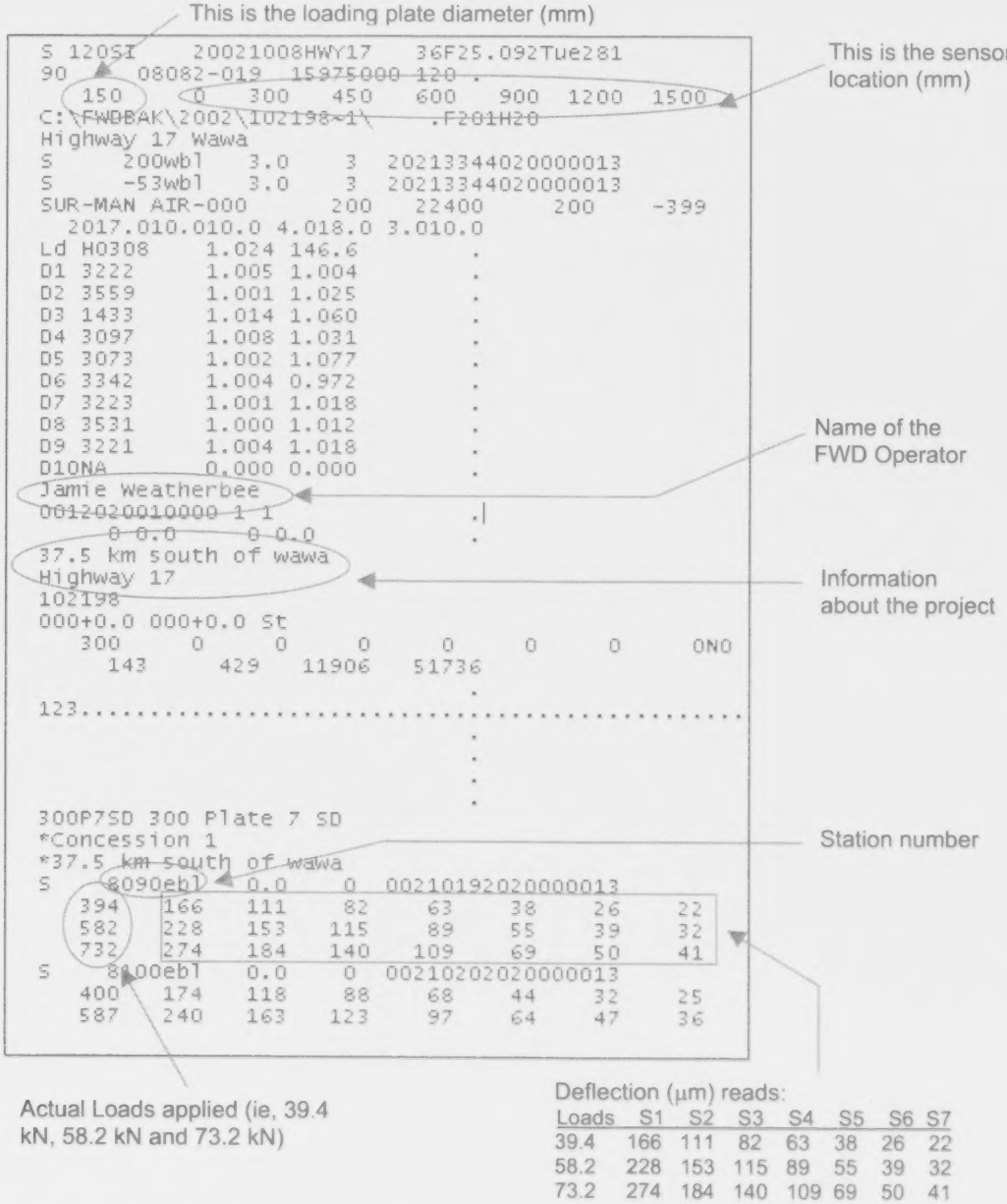
This section discusses some examples of FWD testing data, and how to interpret the raw FWD testing data results.

WHAT IS A GOOD FWD TESTING DATA SET?

A good FWD testing data set should be representative of the pavement structure in terms of the strength and stiffness. The FWD raw data provides the deflection information at different load levels, which indirectly indicates the stiffness of the pavement structure at the test point. Higher deflection implies the pavement structure at the test point is less stiff and vice versa. Therefore, a good pavement structure should have a lower deflection measure.

UNDERSTANDING THE RAW FWD DATA

Following is a sample FWD raw data set. The important information is identified for your reference.


This is the loading plate diameter (mm)
This is the sensor location (mm)
Name of the FWD Operator
Information about the project
Station number
Actual Loads applied (ie, 39.4 kN, 58.2 kN and 73.2 kN)
Deflection (μm) reads:
Loads S1 S2 S3 S4 S5 S6 S7
39.4 166 111 82 63 38 26 22
58.2 228 153 115 89 55 39 32
73.2 274 184 140 109 69 50 41

```
S 120SI    20021008HWY17    36F25.092Tue281
90    08082-019  15975000 120 .
  150     0   300   450   600   900  1200  1500
C:\FWDBAK\2002\102198~1\     .F201H20
Highway 17 Wawa
S     200wbl    3.0     3  20213344020000013
S     -53wbl    3.0     3  20213344020000013
SUR-MAN AIR-000       200    22400      200     -399
  2017.010.010.0 4.018.0 3.010.0
Ld H0308     1.024 146.6          .
D1 3222      1.005 1.004          .
D2 3559      1.001 1.025          .
D3 1433      1.014 1.060          .
D4 3097      1.008 1.031          .
D5 3073      1.002 1.077          .
D6 3342      1.004 0.972          .
D7 3223      1.001 1.018          .
D8 3531      1.000 1.012          .
D9 3221      1.004 1.018          .
D10NA        0.000 0.000          .
Jamie Weatherbee
0012020010000 1 1                .|
     0 0.0     0 0.0             .
37.5 km south of wawa
Highway 17
102198
000+0.0 000+0.0 St
   300     0     0     0     0     0     0     0NO
     143     429   11906   51736
                                  .
123.....................................................
                                  .
                                  .
                                  .
                                  .
300P7SD 300 Plate 7 SD
*Concession 1
*37.5 km south of wawa
S    8090eb1   0.0     0  00210192020000013
   394   166   111    82    63    38    26    22
   582   228   153   115    89    55    39    32
   732   274   184   140   109    69    50    41
S    8100eb1   0.0     0  00210202020000013
   400   174   118    88    68    44    32    25
   587   240   163   123    97    64    47    36
```

Figure 6 – Sample of FWD Raw Data

ASSESSING PAVEMENT STRUCTURE

A good pavement structure usually has a uniform set of data with minimal deflection. Following are examples of a uniform and a variable pavement structure, by plotting the raw FWD testing data:

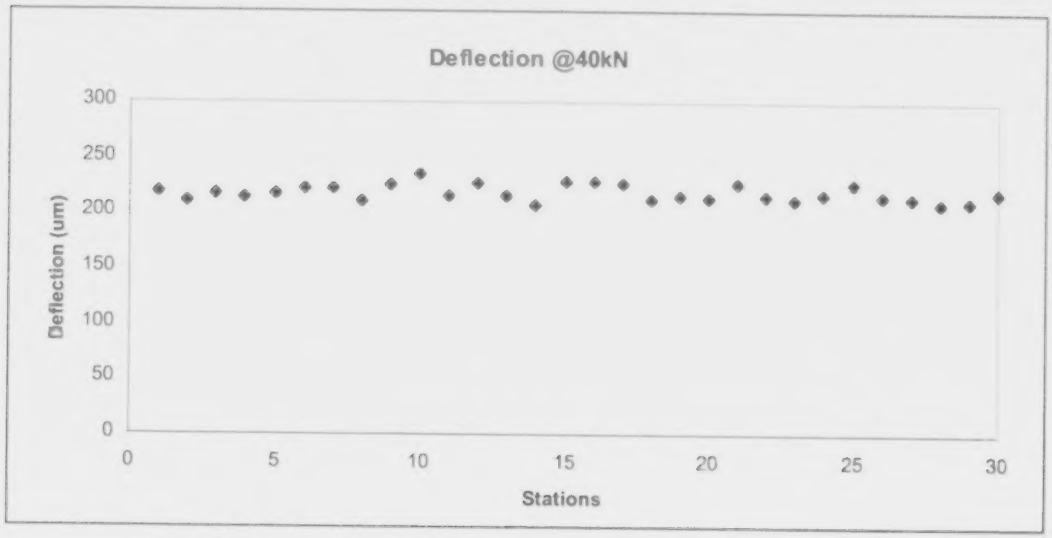


Figure 7 – Sample Uniform FWD Testing Data

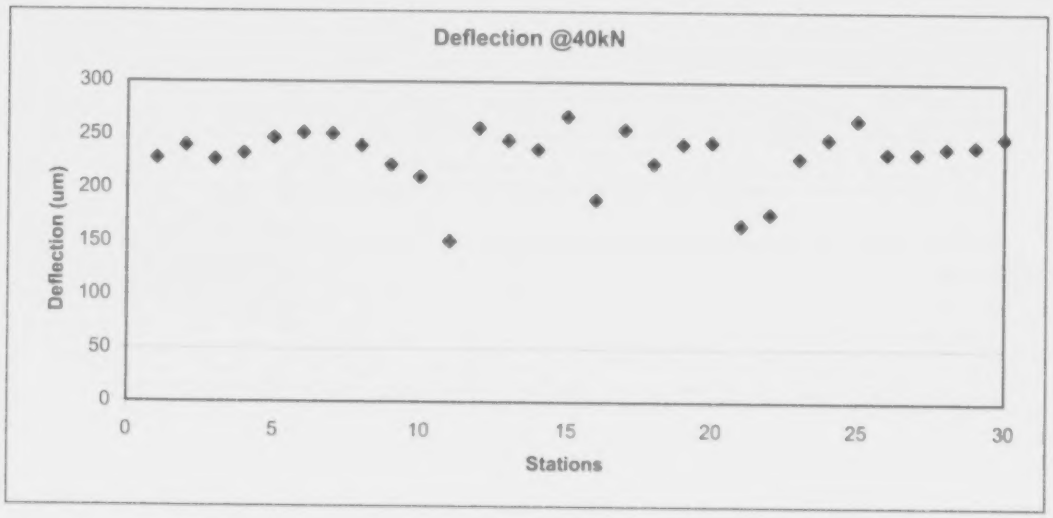


Figure 8 – Sample Non-Uniform FWD Testing Data

Figures 7 and 8 above are plotted based on the 40kN target loading deflections. Figure 7 has a relatively uniform data set with similar deflections around 230 μm; and Figure 8 has a relatively non-uniform data set with scattered deflection points ranging between 150 to 270 μm. Therefore, it is apparent that the pavement structure in Figure 8 has demonstrated a less uniform but overall stiffer response compared to Figure 7.

FWD TESTING DATA ANALYSIS – TYPICAL MODULUS VALUES

As discussed in the *FWD Testing and Analysis* section, one of the FWD testing data analysis outputs is the elastic modulus of each layer. The layer modulus is an indication of the pavement layer stiffness at the time of testing. Following are the typical modulus values for different material layers for reference:

Table 8 – Typical Pavement Modulus Values

Typical Pavement Modulus Values		
Material	**Range (MPa)**	**Typical (MPa)**
Hot Mix Asphalt	1,500 to 3,500	3,000
Portland Cement Concrete	20,000 to 55,000	30,000
Bituminous Treated Base	500 to 3,000	1,000
Cement Treated Base	3,500 to 7,000	5,000
Granular Base	100 to 350	200

If the FWD back-calculation analysis gives a result that is out of this typical pavement modulus range, then the testing may be inaccurate or the back-calculation analysis may not be correct. Further investigation is required to identify the discrepancy before any pavement design is carried out.

Contract Administration

This section discusses the contract administration requirements for performing the FWD testing. The following documents shall be submitted to the Contract Administrator prior to FWD testing:

- Project Specific Quality Control Plan Including:
  - FWD Equipment Specification and Identification
  - Certification of Calibration Reports (refer to *Equipment Calibration* section for details)
    - Annual Referenced Calibration
    - Monthly Relative Calibration
  - Technician Qualification Reports (demonstrated FWD operation experience)
- Health and Safety Plan and Traffic Control Plan that complies with Ontario Traffic Manual Book 7.

The Contract Administrator should verify the aforementioned documentation against the requirements specified in this FWD Testing Guideline prior to commencement of the work.

The Contract Administrator should ensure that the FWD testing is performed according to the proper procedures and requirements as outlined in this guideline, *FWD Operational Procedure to Minimize Errors* subsection, and the project specific Terms of Reference (Appendix).

References

[1] *Transport Research COST 336- Falling Weight Deflectometer*, European Commission, Directorate General Transport, 2000.

[2] *State Use Falling-Weight Deflectometer (FWD) Data to Develop More Cost-Effective Rehabilitation Strategies*, LTPP Publication No. FHWA-RD-2-067, March 2002.

[3] *Standard Method of Test for Pavement Deflection Measurements*, AASHTO Designation T-256. (2001), Washington, DC. 2001.

[4] *Guideline for FWD Testing and Criteria for Concrete Repair*, Ontario Ministry of Transportation - Central Region, Downsview, Ontario, 2002.

[5] *Manual for FWD Testing in the Long-Term Pavement Performance Program (SHRP-P-661)*, Strategic Highway Research Program, National Research Council, Washington, DC, 1993.

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Determination of Insitu Material Properties of Asphalt Concrete Pavement Layers from Nondestructive Tests", Research Results Digest – Number 271, National Cooperative Highway Research Program, Transportation Research Board, December 2002.

Falling Weight Deflectometer Operator's Manual, Texas Department of Transportation, Pavements & Materials Systems Branch, October 2002.

Manual for Condition Rating of Rigid Pavements - SP-026, Ontario Ministry of Transportation, Research & Development Branch, Ontario. September 1995.

Standard Guide for General Pavement Deflection Measurements, ASTM D-4695, Road and Paving Materials.

Appendix: Sample Terms of Reference

Falling Weight Deflectometer (FWD) Testing
Highway 17, from 37.5 km south of Wawa, southerly for 22.4 km

PROJECT DEFINITION

(This section should identify the project location, describe the pavement structure and the data collection scenarios [e.g., network, general project (pre-engineering) or detailed project levels].)

FWD testing is required on Highway 17, from 37.5 km south of Wawa, southerly for 22.4 km. This FWD testing is a general project level data collection effort to evaluate the pavement structure in a section of Highway 17 which was recently rehabilitated using full depth reclamation with expanded asphalt stabilization and overlaid with two lifts of HL-4 hot mix.

EQUIPMENT SPECIFICATIONS

(This section should identify the equipment specification and/or requirements to perform the FWD testing.)

- In general, the Falling Weight Deflectometer should consists of the following components and comply with the specification described below:
    - Load Pulse with target peak load of 75 +/- 5 kN
    - Loading Plate with a rubber pad of at least 5 mm thickness glued to the bottom to allow uniform load application onto the pavement surface
    - A minimum of seven Deflection Sensors with radial line distances from 0 to 250 cm
    - Load Cell with reading resolution of 0.1kN or better
    - Thermometer with reading resolution of 0.5 °C or better

- The FWD equipment shall have been SHRP calibrated in (*insert year*). The servicing date should be within one year after the date of full calibration
    - Reference Calibration (annually)
    - Relative Calibration (monthly)

- An up-to-date calibration report should be submitted by the consultant prior to commencement of FWD testing. The full FWD certification of calibration report should consist of the following:

- Print out of the FWD field program screen including
  - FWD identification and calibration date
  - Transducer set-up and calibration factors
  - Voltages
  - Load cell calibration
- All printouts from the FWDREFEL software
- The final printouts from the FWDCAL2 software for all relative calibration trials
- The final calibration computation worksheet

PROJECT PARTICULARS

(This section should identify the test protocol, including traffic control, testing / procedural requirements.)

- FWD deflection basin tests on Highway 17 south of Wawa (22.4 km) with the location and frequency specified below:
  - Driving lane, outer wheel path
  - Test interval in each direction is every 200 m
  - Staggered eastbound and westbound directions
  - Total test points (both directions) is 224 FWD tests

- Additional FWD deflection basin tests on a 305 m control section with the location and frequency specified below:
  - South of the Baldhead River West Branch (Asselin Township Sta. 12+895 to 13+200)
  - Driving lane, outer wheel path
  - 15 test points for each direction
  - Staggered eastbound and westbound directions
  - Total test points (both directions) is 30 FWD tests

- Four target load drops for flexible pavement, each should have one load drop at each of four load level:
  - Target loads drops at 25, 40, 55, and 70 kN

- Deflection basin test sensor configuration should be as follow:
  - 0, 20, 30, 45, 60, 90, 150 cm

- Allowable FWD testing temperature ranging from 0 to 20 °C, without frost

- Minimum of two coreholes/borecoles are required (start and end of the test section) to measure pavement temperature and/or pavement depths

- Test location should be free from all rocks and debris to ensure loading plate could be properly seated

- Traffic Control and Occupational Health and Safety
  - A Health and Safety Plan should be submitted prior to FWD testing
  - All work carried out should comply with Ontario Traffic Manual Book 7

PROJECT DELIVERABLES

(This section should identify the deliverables [output & analysis requirements] from the consultant.)

- Deflection data (normalized to 40kN and 21 °C temperature) are required at each test point with stations to identify test location.

- Back-calculated resilient moduli are required at each test point for each layer as follows:
  - Hot mix asphalt
  - Expanded asphalt stabilized base
  - Granular base and subbase
  - Subgrade

  Back calculation of pavement layer moduli shall be carried out using updated SHRP or AASHTO approved software.

- Average deflection and pavement modulus are required for Highway 17 from 37.5 km south of Wawa, southerly for 22.4 km.

- Average deflection and pavement modulus are required for the identified 305 m control section.

- All FWD raw data files (unedited electronic copy with *.fwd, f25 or f20 file format) shall be incorporated into the final report package.

SCHEDULE AND COMPLETION DATE

(This section should identify the FWD testing completion date, as well as the final report submission deadline.)

- FWD testing shall be completed on or before October 18, 2002.
- Final report package shall be submitted on or before November 22, 2002.

CONTRACT ADMINISTRATION

(This section should identify any documentation or procedural requirements for the CA to follow.)

Following are the documentation submission requirements to the Contract Administrator prior to FWD testing:

- Project Specific Quality Control Plan Including:
  - FWD Equipment Specification and Identification
  - Certification of Calibration Reports (refer to *Equipment Calibration* section for details)
    - Annual Referenced Calibration
    - Monthly Relative Calibration
  - Technician Qualification Reports (demonstrated FWD operation experience)
- Health and Safety Plan and Traffic Control Plan that complies with Ontario Traffic Manual Book 7

Contract Administrator shall verify the aforementioned documentation against the requirements specified in this Terms of Reference prior to commencement of the work.

The Contract Administrator shall ensure that the FWD testing is performed according to the proper procedures and requirements as outlined in the FWD guideline, *FWD Operational Procedure to Minimize Errors* subsection of the ***FWD Testing Guideline***, and this *Terms of Reference*.

PROJECT COST

(This section should identify the quotation requirements for completing the project.)

The consultant will be required to submit a quote with the following breakdowns:

- Cost per each FWD deflection basin test point
- Cost of mobilization
- Expenses per day
- Total project cost including all the necessary documentation
- Occupational Health and Safety / Traffic Control Plan Review Meeting